GROUND PENETRATING RADAR (GPR): A TOOL FOR MONITORING BRIDGE SCOUR

Doyle J. Webb* (joewebb@exate.com), Neil L. Anderson* (nanders@umr.edu),
Tim Newton+ (newtot@modot.state.mo.us), Steve Cardimona* (cardi@umr.edu)
and Ahmed Ismail (aib57@umr.edu)

*Department of Geology and Geophysics, University of Missouri-Rolla, Rolla, MO 65401
+Missouri Department of Transportation, Jefferson City, MO

Abstract

The University of Missouri-Rolla (UMR) and the Missouri Department of Transportation (MoDOT) acquired ground penetrating radar (GPR) profiles across selected streams and drainage ditches at ten bridge sites in southeast and central Missouri. The objective was to determine if GPR is an effective tool for monitoring bridge scour and estimating the depths and breadths of in-filled scour features.

The interpretation of the suite of acquired GPR profiles indicates the tool can be used to accurately estimate water depths in shallow fluvial environments (<20 feet). In certain instances, in-filled (paleo) scour features can also be imaged and mapped. This later information is important because it provides information about maximum scour during peak flow periods.

GPR has certain advantages over alternate methods for estimating water depths. GPR can provide an essentially continuous profile-type image of the stream channel and the sub-water bottom sediment along the traverse selected. The GPR antenna are non-invasive and can be moved rapidly across (or above) the surface of a stream at the discretion of the operator. Additionally, the GPR tool does not need to be physically coupled to the water surface and can be operated remotely, ensuring that neither the operator nor equipment need be endangered by floodwaters. Perhaps the most significant disadvantage of GPR is that the tool does not work well in “clayey” sedimentary environments.

Introduction

The determination of seasonal variations in water depth and the assessment of erosional and depositional patterns in the vicinity of existing or planned bridge piers (monitoring of bridge scour) is essential to understanding the fluvial scour process on a site-specific scale. The design of preventative (during bridge construction) or remediation measures is most efficient and cost-effective if the local scour process is understood. Unfortunately, riverbed scour occurs mostly during high flow stages. Scour depth/breadth information can be very difficult (and dangerous) to acquire at such times. Additionally, scour features are often in-filled as peak flow subsides making the direct measurements of maximum scour depth/breadth essentially impossible after the fact.

In an effort to assess the utility of GPR when employed as a bridge scour monitoring/investigation tool, UMR and MoDOT acquired GPR profiles across streams and drainage ditches at ten different bridge sites in southeastern and central Missouri. The GPR profiles were acquired using a GSSI SIR-10B radar unit equipped with a 200 MHz monostatic antenna. (At some sites, duplicate GPR profiles were acquired using an additional higher frequency antenna.) A scaled rod was used to manually measure stream depths at specific control locations for the purpose of ground-truthing.

The report submitted to MoDOT included a brief synopsis of the bridge scour process, an overview of the GPR method, short summaries of alternate methods for studying bridge scour, and example interpreted GPR profiles.

Types of Source: Classification

The erosion of riverbed material at bridge sites is a result of natural stream processes, particularly seasonal variations in water depth and velocity. Indeed, maximum scour depths are often estimated by assuming that scour depth is proportional to the rise of the water surface elevation (Xanthakos, 1995). Bridge scour is also influenced by bridge components such as piers, abutments, roadway embankments, and the superstructure itself, and is classified as general, contraction, or local (Figure 1).

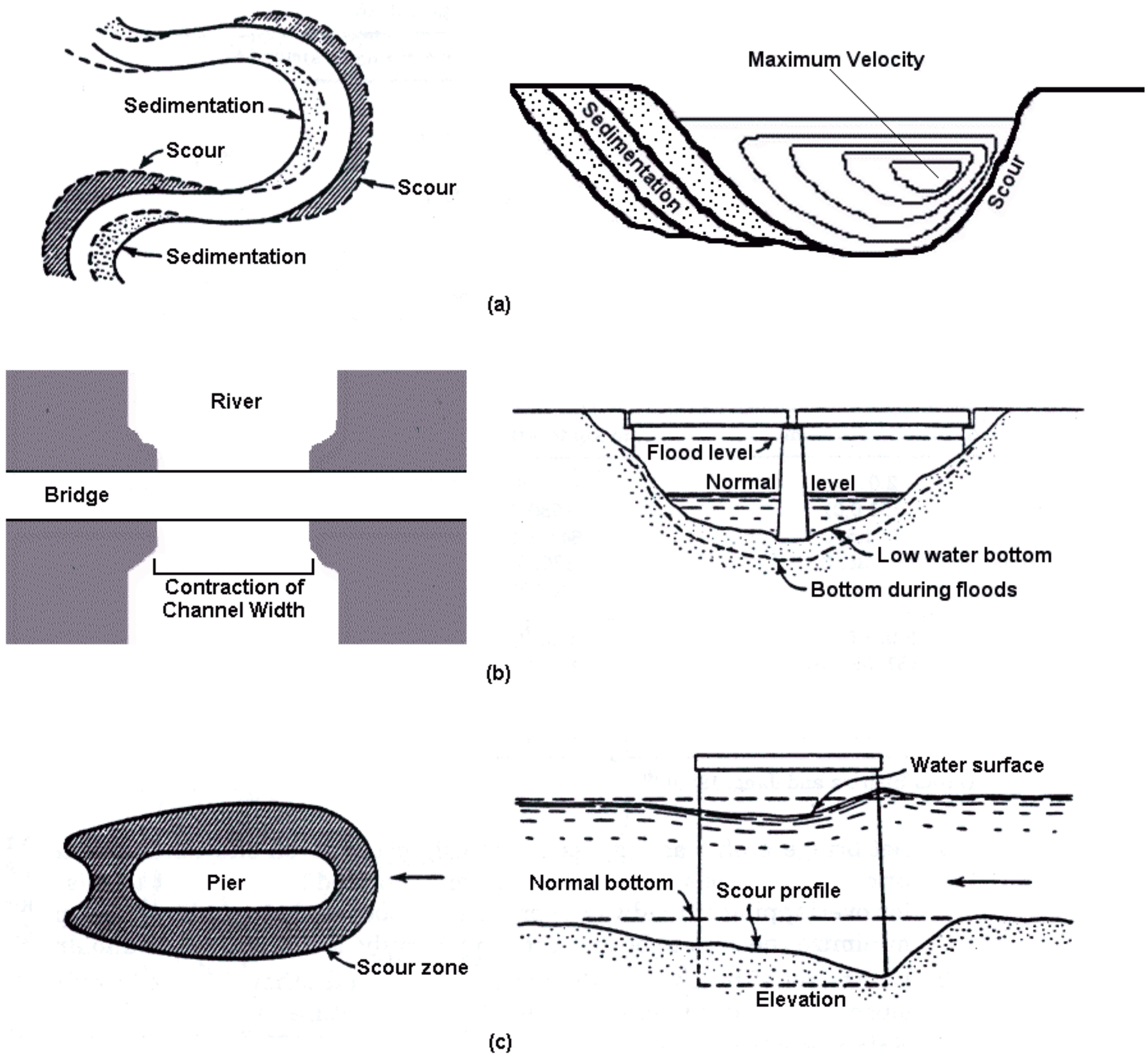

Figure 1. Forms of scour in waterways: (a) general scour, (b) contraction scour, and (c) local scour (after Xanthakos, 1995). Left side depicts plan view; right side depicts cross-section.

General Scour is illustrated in Figure 1a. In this process, progressive erosion at the outer bend along a meandering stream causes the progressive lateral shifting of the stream channel and attendant variations in water depths. General scour can result in the undermining of abutments if certain precautionary measures (such as the placement of concrete or asphalt mats over the riverbank and the installation of abutment foundations below the lowest depth of possible scour) are not taken.

Contraction Scour is illustrated in Figure 1b. In this process, the narrowing of the waterway at a bridge site increases water velocity and accentuates erosion. A remedy is to enlarge the channel or ensure the channel under the bridge is the same size as the channel adjacent to the bridge.

Local Scour is illustrated in Figure 1c. In this process, river obstructions such as bridge piers cause the contraction of channel cross section resulting in higher flow velocities and accentuated erosion. The magnitude of scour is dependent upon pier configuration and inclination with respect to flow, contraction of waterways, and volume of debris accumulated at bridge.

Geophysical Methods for Evaluating Scour

Several geophysical techniques are commonly used to measure water depths and/or the depth/breadth of in-filled scour features. Techniques include reflection seismic profiling, echo sounding (in continuous or spot survey mode) and electrical conductivity probing. The GPR tool is presented herein as an effective alternative in certain circumstances. Each tool has characteristic strengths and weaknesses.

Reflection Seismic Profilers

The reflection seismic profiling technique typically employs a coupled acoustic source transducer/receiver transducer placed immediately beneath the surface of the water. The acoustic source transducer produces a short period (frequencies in kilohertz range) pulsed acoustic signal at regular time or distance intervals as it is towed across the surface of the water (Figure 2). The high-frequency pulsed seismic signal propagates through the water column and into the sub-water bottom sediment. Some of the acoustic energy is reflected at the water bottom and at other prominent acoustic impedance interfaces (e.g., lithological and/or facies interfaces; Figure 2) and returned to the receiver. The receiver measures and digitally records the magnitude of the reflected energy as a function of two-way travel time. Magnitude of reflected signal vs. arrival time for each source/receiver location is visually displayed as a time-trace. Time-traces from adjacent source/receiver locations are plotted side-by-side forming an essentially continuous time-depth profile of the stream bottom and shallow sub-strata (including in-filled scour features). Estimated seismic interval velocities can be used to transform the time-depth profile into a depth profile (Figure 3). Water velocities are a function of suspended sediment load and can vary appreciably.

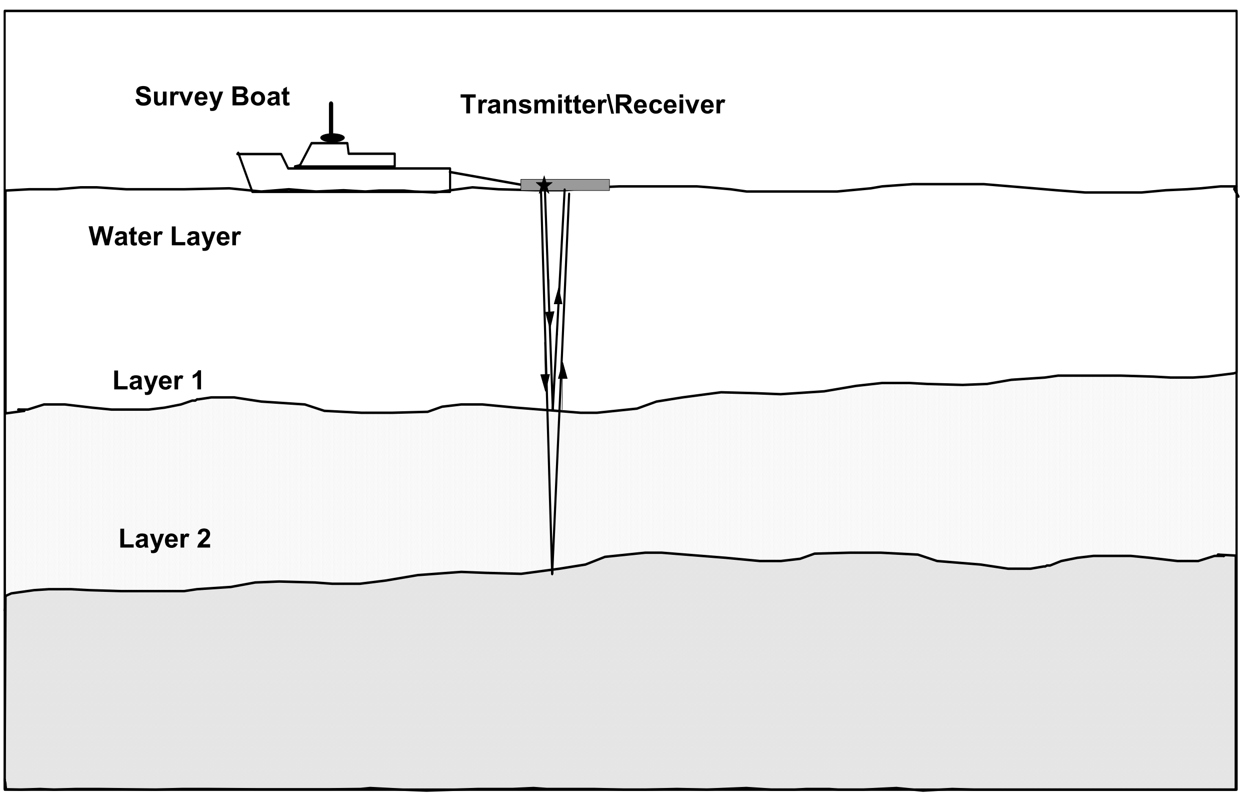

Figure 2. Schematic diagram for the seismic profiling survey showing coupled source/receiver data acquisition using a small boat. (Down-going and up-going ray-paths are generally treated as though they were perpendicular to reflecting horizons.)

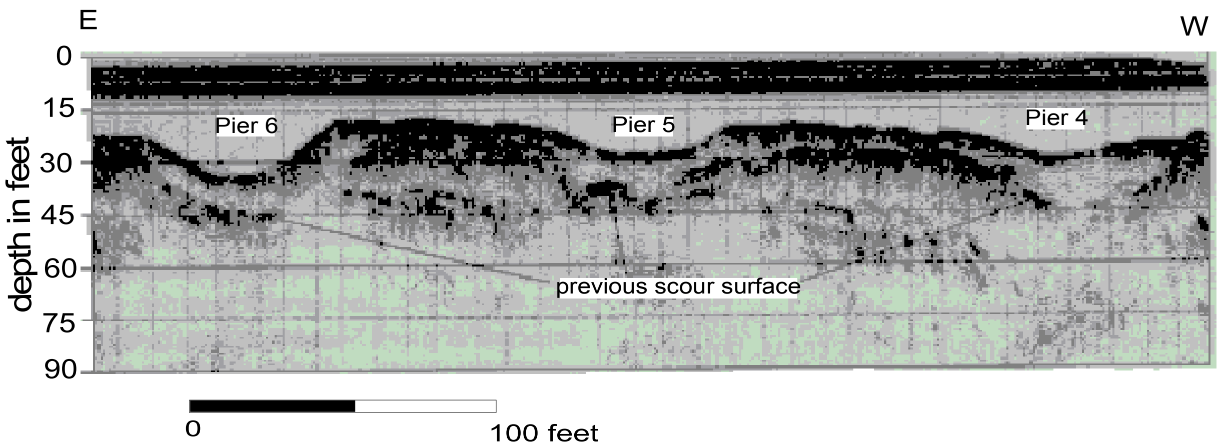

Figure 3. Example 7-kilohertz continuous seismic-reflection profiling data (after Placzek and Haeni, 1993).

The main advantages of reflection seismic profiling are as follows:

1. The tool can provide an accurate depth-structure model of the water bottom (to depths on the order of hundreds of feet).
2. Post acquisition processing (including 2-D migration) can be applied.
3. The tool can provide an accurate image of the sub-water bottom sediment to depths on the order of tens of feet (dependent upon the frequency of the acoustic source). Lithological/facies units with thickness on the order of 0.3ft can be imaged with higher-frequency antenna (14 kHz units).

The main disadvantages of the reflection seismic profiling tool are as follows:

1. The source and receiver need to be submerged. Profiles cannot be extended across emerged sand bars or onto the shore.
2. The equipment is relatively expensive (hardware and software).
3. Data may be contaminated by noise (multiple reflections, and echoes from the shoreline, water bottom and/or bridge piers).

Echo Sounders (Fathometers)

Echo sounders (fathometers) are similar to the reflection seismic profilers in that they also employ a coupled acoustic source transducer/receiver transducer placed immediately beneath the surface of the water. Echo sounders differ from reflection seismic profilers in that they emit a higher frequency acoustic source pulse (dominant frequency in 100 kHz range), some of which is reflected at the water bottom, returned to the receiver, and stored digitally (Figure 4). (Because of the rapid attenuation of the high frequency pulsed acoustic energy, relatively little signal is transmitted into or reflected from within sub-water bottom sediment.) Traces from adjacent source/receiver locations are plotted side-by-side to form an essentially continuous time-depth profile of the stream bottom. Figure 4 depicts an example fathometer depth profile recorded data at new Baldwin Bridge, Old Saybrook, Conneticut. Estimated seismic interval velocities can be used to transform the time-depth profile into a depth profile (Figure 5). Water velocities are a function of suspended sediment load and can vary appreciably.

The main advantages of the echo-sounding tool (in continuous mode) are as follows:

1. The tool can provide an accurate depth-structure model of the water bottom (if acoustic velocities are known).
2. Post acquisition processing (migration) can be applied.

The main disadvantages of the echo sounding tool (in continuous mode) are as follows:

1. The source and receiver need to be submerged. Profiles cannot be extended across emerged sand bars or onto the shore.
2. The equipment is relatively expensive (hardware and software).
3. Data may be contaminated by noise (multiple reflections, and echoes from the shoreline, water bottom and/or piers).

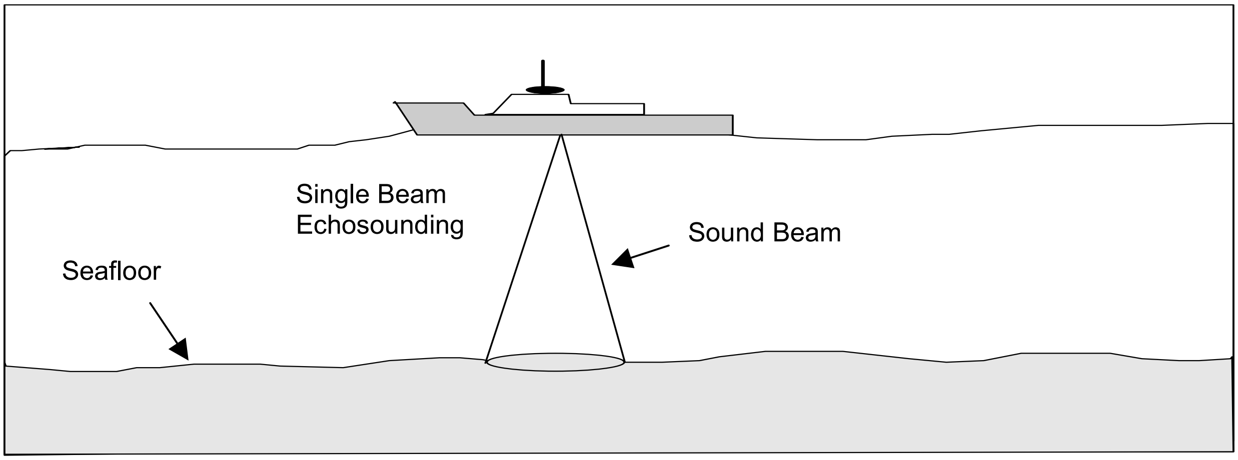

Figure 4. A schematic diagram showing collection of echo sounding data.

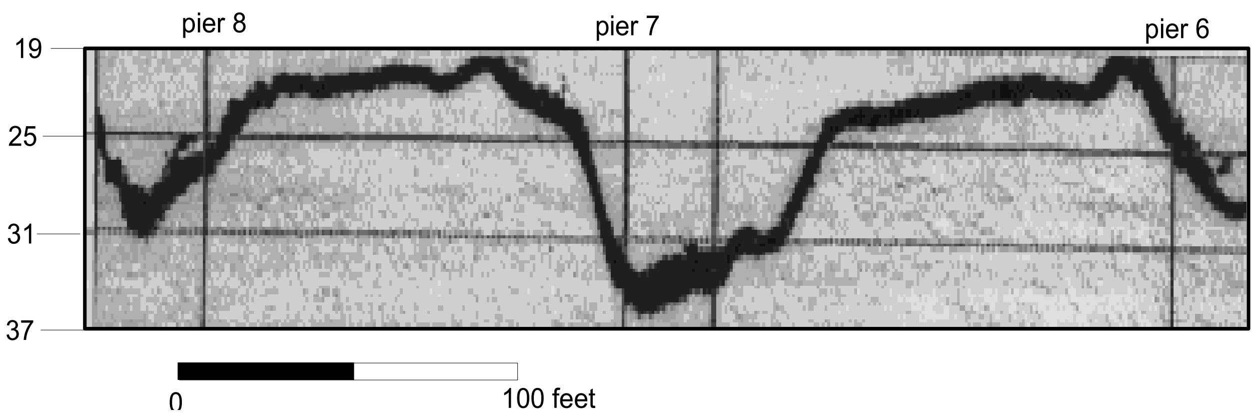

Figure 5. Unpositioned 200-kilohertz fathometer data collected 15 feet upstream from the new Baldwin Bridge, Old Saybrook, Conn. (after Placzek et al., 1993).

4. Post acquisition processing (migration) may be required in areas where significant structural relief is present.
5. The tool cannot be used to image in-filled scour features within sub-water bottom sediments.

Echo sounders are also employed in a spot survey mode. In this type of survey, sounding data (single reflection traces) are acquired at irregularly (or uniformly) spaced intervals (typically on the order of feets) at the water surface. The first high-amplitude reflected event is usually interpreted to be the water bottom reflection. Note, that spot data usually cannot be accurately migrated because of aliasing problems.

The main advantages of the echo sounders (in spot mode) are as follows:

1. The tool can provide an accurate depth-structure model of the water bottom if acoustic velocities are known.
2. The equipment is relatively inexpensive.

The main disadvantages of the echo sounders (in spot mode) are as follows:

1. The source and receiver need to be submerged. Data cannot be acquired across emerged sand bars or onto the shore.
2. Data may be contaminated by noise (i.e., the first high amplitude event may not be from the water bottom).
3. Water depths may be significantly underestimated in areas of extreme water bottom relief (curved surfaces with radii less than water depth).

Electrical Conductivity Probes

Electric conductivity probes measure the ability of a solution to conduct an electric current between two electrodes. In solution, current flows by ion transport. Therefore, an increasing concentration of ions in the solution will result in higher conductivity values. Conductivity Probes actually measure conductance, (the reciprocal of resistance). When resistance is measured in ohms, conductance is measured using the SI unit, siemens (formerly known as a mho). An example electrical conductivity probe is shown as Figure 6.

Use of the electrical conductivity probe to measure the depth to riverbed is based on the principle that the conductivity of the riverbed and the river water differ. (The nature of suspended sediments, dissolved ions and chemical characteristics of water determines its conductivity. Parent materials and the composition of the water in the sediments determines the electrical conductivity of the riverbed.) In this technique, multiple conductivity sensors are placed on a probe, which is driven vertically into the riverbed at the desired location and left for periodic monitoring. At least one of the probe's sensors extends above the riverbed, while multiple sensors are placed within the sub-water bottom sediments (Hayes 1995). If scour occurs at the location of the probe to the extent that one or more previously buried sensors are exposed to water, these newly exposed sensors will measure the conductivity of the flowing water instead of the sediments in the riverbed. Hayes (1995) states the method works well only if the conductivity of the riverbed and water differ significantly. Hayes (1995) also states that the tool cannot be used for direct measurement of in-filled scour features.

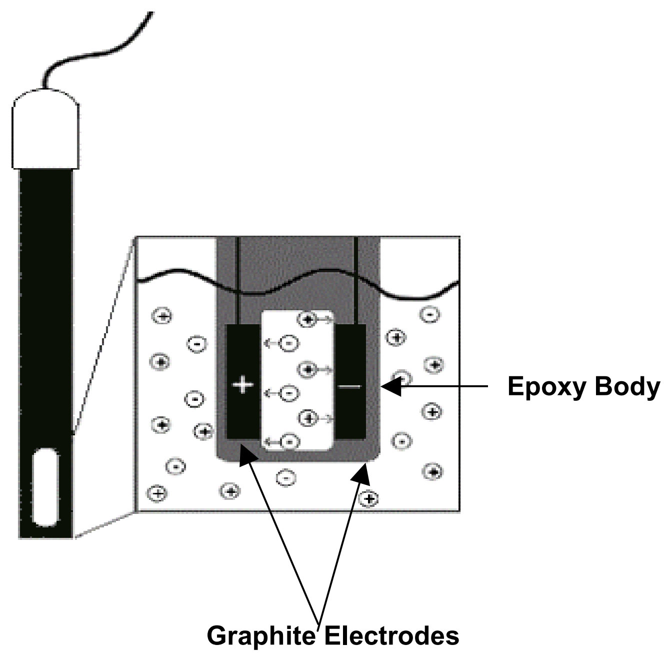

Figure 6. Electrical conductivity probe used for the educational purposes (after Vernier Software and Technology, 2000).

The main advantages of the electrical conductivity probe method are as follows:

1. The tool allows for long term monitoring.
2. The method is relatively inexpensive.

The main disadvantages of the electrical conductivity probe method are as follows:

1. The tool monitors scour only at the location of the probe.
2. The tool can be used effectively only where water and sediment conductivities differ appreciably.
3. The tool may pose a hazard to navigation.
4. Scour features can be underestimated.
5. The tool cannot be used to image scour features within the sub-water bottom sediments.

Ground Penetrating Radar (GPR)

The ground penetrating radar (GPR) tool typically employs a coupled source antenna/receiver antenna placed on or immediately above the surface of the water as it is shown in Figure 7. The source transducer produces a short period (frequencies in megahertz range) pulsed electromagnetic signal at regular time or distance intervals as it is towed across or above the surface of the water. Some of this pulsed electromagnetic (EM) energy is reflected from the water bottom and other prominent dielectric interfaces (facies contacts), and returned to the receiver. The arrival time and magnitude of the reflected energy is recorded at the surface by the receiver antenna (Figure 8). Traces from adjacent source locations are generally plotted side-by-side to form an essentially continuous time-depth profile of the stream bottom and shallow sub-strata (including in-filled scour features). Estimated EM velocities can be used to transform the time-depth profile into a depth profile (Figure 9). Velocities are a function of suspended sediment load, and can vary appreciably.

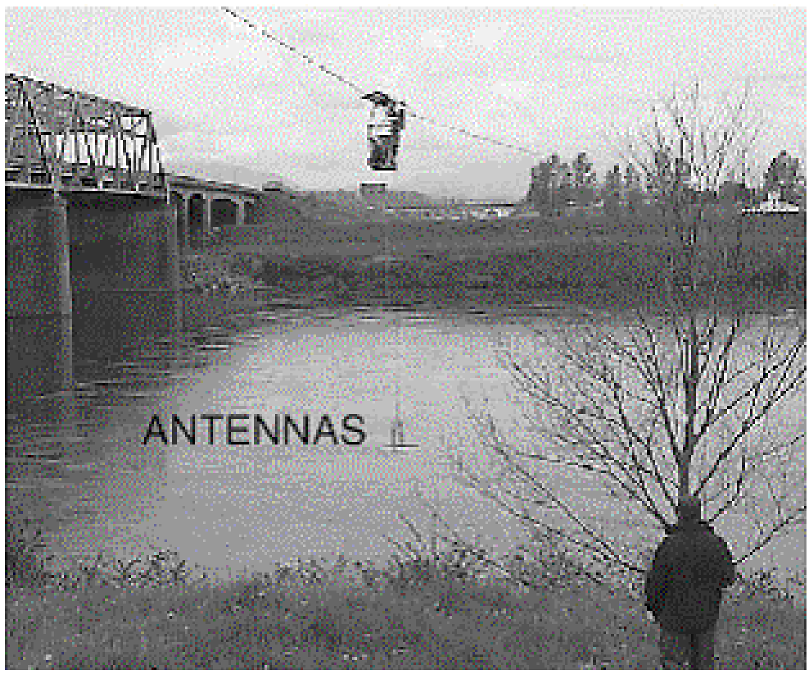

Figure 7. GPR system mounted inside cable car with 100MHz antenna suspended up to 10 feet above the water surface.

The main advantages of the GPR profiling tool are as follows:

1. GPR can provide an essentially continuous image of the stream channel and the sub-water bottom sediment along the route selected.
2. The GPR tool can provide an accurate depth-structure model of the water bottom and sub-water bottom sediments (to depths on the order of 30 feet). Lithological/facies units with thickness on the order of 0.3 feet can be imaged with intermediate-frequency antenna (200 MHz).
3. The GPR antennae are non-invasive and can be moved rapidly across (or above) the surface of a stream at the discretion of the operator. The GPR tool does not need to be physically coupled to the water surface and can be operated remotely, ensuring that neither the operator nor equipment need be endangered by floodwaters.
4. Profiles can be extended across emerged sand bars or onto the shore.
5. The digital GPR data can be stored, and post acquisition processing (including migration) can be applied.

The main disadvantages of the GPR profiling tool are as follows:

1. The equipment is relatively expensive (re: hardware and software).
2. Data may be contaminated by noise (multiple reflections and echoes from pier footings).
3. Post acquisition processing (migration) may be required in areas where significant structural relief is present.
4. The tool is not normally effective when water depths exceed 30 feet.
5. The tool cannot be used in saline waters.
6. The tool does not work well in clayey environments.

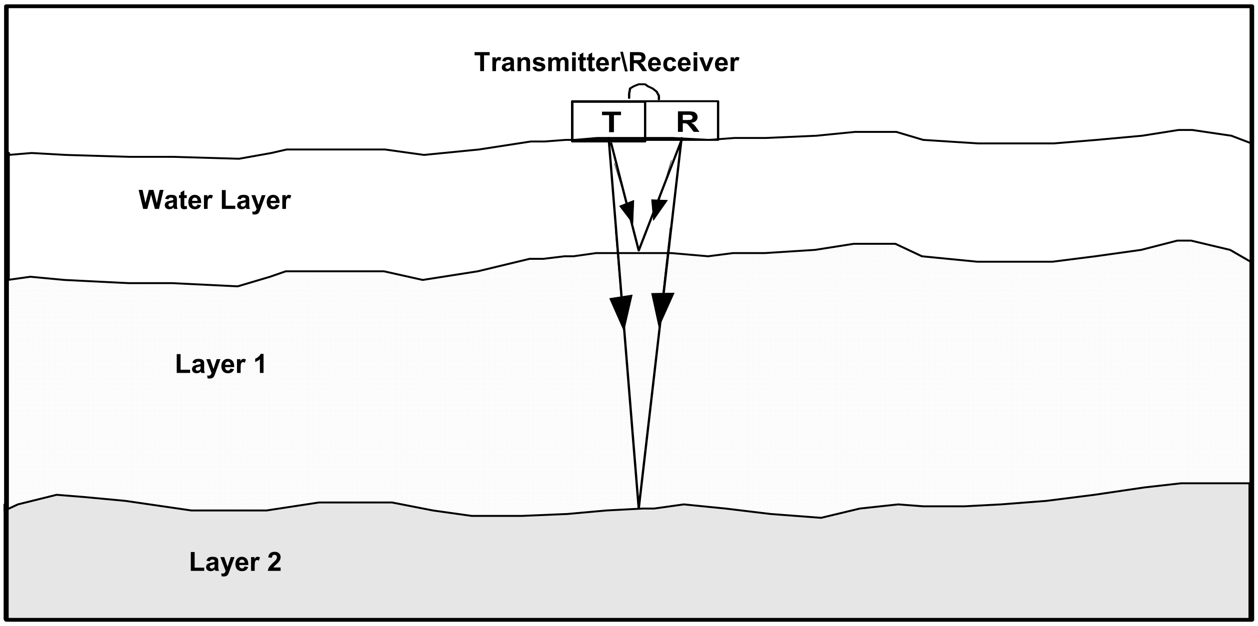

Figure 8. Principles of GPR technique. (Down-going and up-going ray-paths are generally treated as though they were perpendicular to reflecting horizons.)

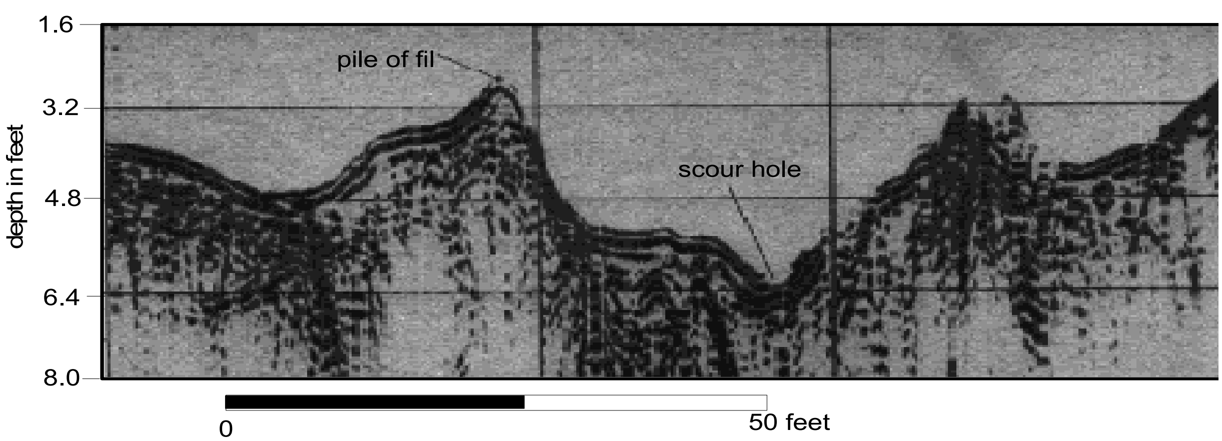

Figure 9. Example 300-megahertz GPR profile collected at the Route 4 Bridge, Farmington, Connecticut (after Placzek and Haeni 1993).

Acquisition of Ground Penetrating Radar at Ten Bridge Sites

In an effort to assess the utility of GPR when employed as a bridge scour investigation tool, GPR profiles were acquired at ten different bridge sites in southeastern and central Missouri. River-bed sediment at all sites consisted of clean clastics, and quality GPR data were expected. A Geophysical Survey Systems (GSSI) SIR-10B unit equipped with a 200 MHz antenna was employed. A sampling rate of 50 scans/second and ranges (trace lengths) between 125 and 350 nanoseconds were employed. At some sites, duplicate profiles were acquired using a 400 MHz antenna.

At each bridge site, GPR profiles were collected both parallel and perpendicular to current flow (Figure 10). At some bridge sites, GPR data could not be collected immediately adjacent to piers, due to obstructions (usually snagged debris). Data were acquired by maneuvering the antenna across the surface of the water in one of three ways: from the bridge deck, manually or by boat. The acquisition method used at each of the ten bridges investigated is displayed in Table 1.

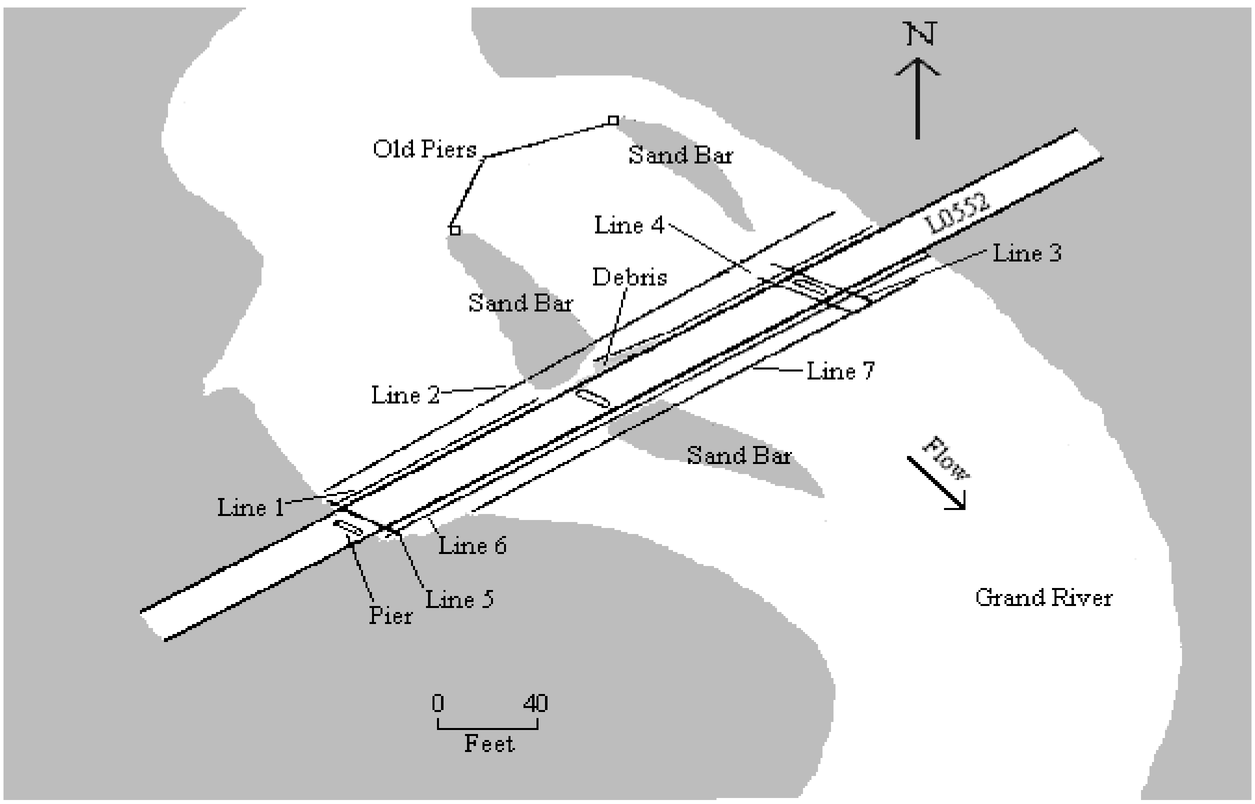

Figure 10. Survey Site 3, Grand River, Livingston, Missouri. Profiles were acquired either parallel (e.g., lines 3, 4 and 5) or perpendicular (e.g., lines 1, 2, 6 and 7) to current flow.

Processing of GPR Data

The acquired GPR data were processed on a Pentium PC using the commercial processing package RADAN. The following run stream was employed.

1. Distance normalization
2. Horizontal scaling (stacking)
3. Vertical frequency filtering
4. Horizontal filtering
5. Velocity corrections
6. Migration
7. Gain

The applied processing steps increased the interpretability of the GPR profiles by removing unwanted random noise and enhancing the amplitude of events of interest (reflections from water bottom and base of in-filled scour features). Unfortunately some of the GPR data were contaminated by high-amplitude water-bottom multiple reflections which could not be removed effectively using the RADAN software. These multiple events arrived after the primary water bottom reflection and in places mask reflections from the base of in-filled scour features.

Site #	Bridge ID Number	Location (County)	Waterway	Height of Bridge above Water (ft)	Maximum Water Depth (ft)	Data Collection Method
1	A-3708 A-3709	Butler	St. Francis River	31	16.6	Bridge deck
2	L927 A5648	Stoddard	Wahite Ditch # 1	Not measured	5.9	Bridge deck
3	L05552	Livingston	Grand River	40	5.5	Wading
4	A-2867	Chariton	Grand River	Not measured	7.6	Boat
5	L-302	Dunklin	Elk Chute ditch	20	3.2	Wading
6	A-2336	Dunklin	Drainage Ditch # 259	21	3.8	Wading
7	A-2333	Dunklin	Drainage Ditch # 1	22	4.9	Wading
8	A-2332	Dunklin	Drainage Ditch # 81	19.8	7.7	Bridge deck
9	A-2334	Dunklin	Drainage Ditch # 66	24.3	3.5	Wading
10	A-2334	Dunklin	Drainage Ditch # 251	22	7	Wading

Table 1. Site logistics and characteristics. Example GPR profiles from Sites 1, 6, 7 and 10 are incorporated into this paper.

Interpretation of Example GPR Profiles

GPR Profiles Acquired Parallel to Flow

Selected, representative GPR profiles (parallel to flow) from sites with different channel characteristics are presented in this section. Study Sites 6 and 7 are shown as Figures 11 and 13, respectively. Representative versions of example GPR profiles are shown in Figures 12 and 14. Note that river-bed sediment at all sites consisted of essentially clean clastics, and quality GPR images of sub-bottom strata were acquired. If significant clay had been present in the sedimentary section, the GPR tool would not have provided quality images of sub-bottom sediment.

In Figures 12 and 14, non-interpreted stacked, migrated, and velocity-corrected GPR sections are presented as captions a, b, and c, respectively. Interpreted stacked, migrated, and velocity-corrected GPR sections are shown as captions d, e, and f, respectively. The depth scales on the stacked and migrated sections were calculated using EM (electromagnetic) water velocities only. As a result, the estimated water bottom depths on the stacked and migrated sections are relatively accurate, however depths to sub-water bottom structures (including in-filled scour features) are inaccurate. In contrast, scaled depths on the velocity-corrected profiles were calculated using different EM velocities for the water and sub-water bottom sediment. Estimated depths on the velocity-corrected profiles are therefore more accurate, particularly within the sub-water bottom section. (Note: Water velocities were estimated on the basis of known water depths and recorded GPR transit times. Sub-water bottom velocities were estimated on the basis of on-site field tests during which metal plates were buried beneath fluvial sediment.)

The arrows on Figures 12 and 14 represent flow directions. The superposed gray line on the interpreted GPR profiles represents the interpreted water bottom. The superposed white line on the interpreted GPR profiles represents reflections from the base of interpreted in-filled scour features. The thickness of in-filled scour features (represented by "S") can be estimated by measuring the distance from the white line to the top of the gray line on velocity-corrected profiles (only). The maximum amount of scour and in-filled scour at each site is listed in Table 1. Piers along the profile are displayed as rectangular columns on the sections. Reflections from the flanks or footings of some of piers are characterized as prominent diffractions on the GPR profiles.

Example Profile 4, Site 6 (Figure 11): The Site 6 bridge, located on Highway 164, crosses a drainage ditch near the town of Kennet, Missouri. GPR profile 4 (Figure 12) was acquired parallel to current flow, and immediately adjacent to two piers. The reflection from the water bottom is clearly evident on all of the processed profiles. Diffractions originating from one of the pier footings are also evident on all profiles, including the migrated sections. (Note, the GPR data were migrated using the water velocity only (limitation of RADAN software), and as a result the diffractions originating from the sub-water bottom footing were not effectively collapsed.) Water bottom depths (gray reflector) can be estimated most accurately from the analysis of the migrated GPR profiles. The depths and thickneses of sub-water bottom layers (in-filled scour features) is accurately depicted only on Figures 12c and 12f. The first-order water bottom multiple is labeled on the GPR profiles.

Example Profile 3, Site 7 (Figure 12): The Site 7 bridge, located on Highway 164, crosses a drainage ditch near the town of Kennet, Missouri. GPR profile 3 (Figure 13) was acquired parallel to current flow, and immediately adjacent to a pier. (The diffractions originating from the pier footings are evident on the stacked, migrated and velocity-corrected profiles.) The reflection from the water bottom is clearly evident on all of the processed profiles. The data were migrated using the water velocity only, and as a result the diffractions originating from the sub-water bottom footing were not effectively collapsed. Water bottom depths (gray reflector) can be estimated most accurately from the analysis of the migrated GPR profile. The depth and thickness of sub-water bottom layers (in-filled scour features) is accurately depicted only on Figures 14c and 14f. The first-order water bottom multiple is labeled on the GPR profiles, as is the multiple originating from the footing of the pier.

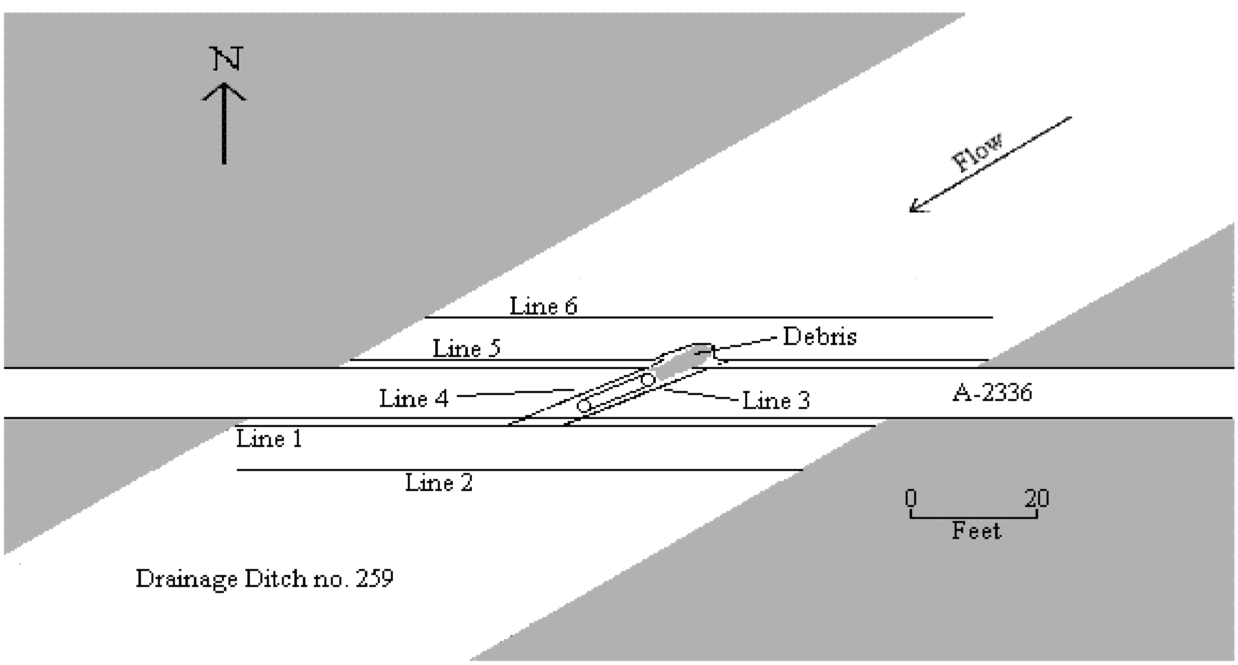

Figure 11. Survey Site 6 (Table 1), Drainage Ditch # 259, Dunklin County, Missouri.

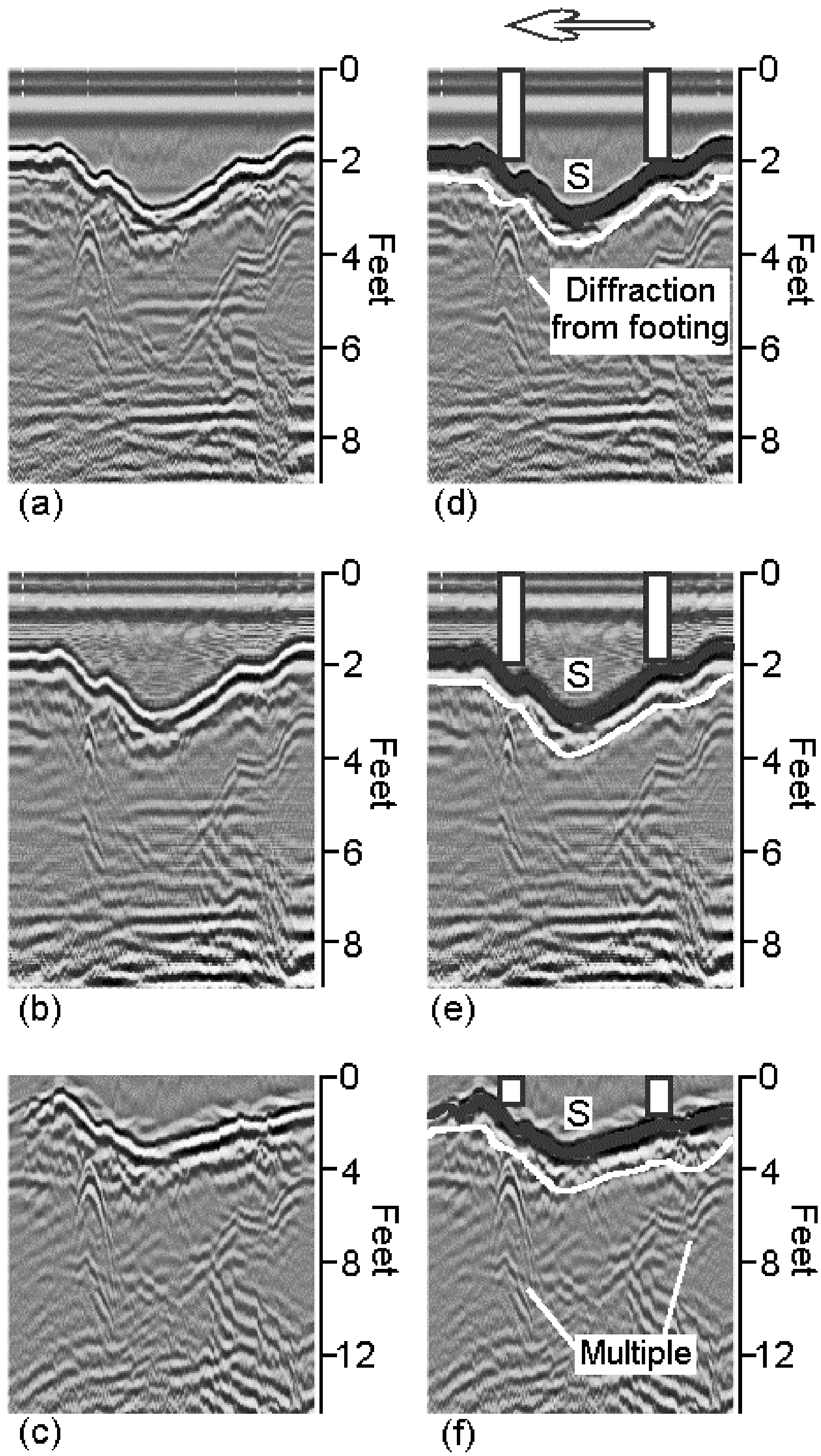

Figure 12. Profile 4, Site 6 (Figure 11): (a) stacked; (b) migrated; (c) velocity-corrected; (d) interpreted stacked; (e) interpreted migrated; and (f) interpreted velocity-corrected. Gray and white lines identify water bottom and extent of in-filled scour, respectively.

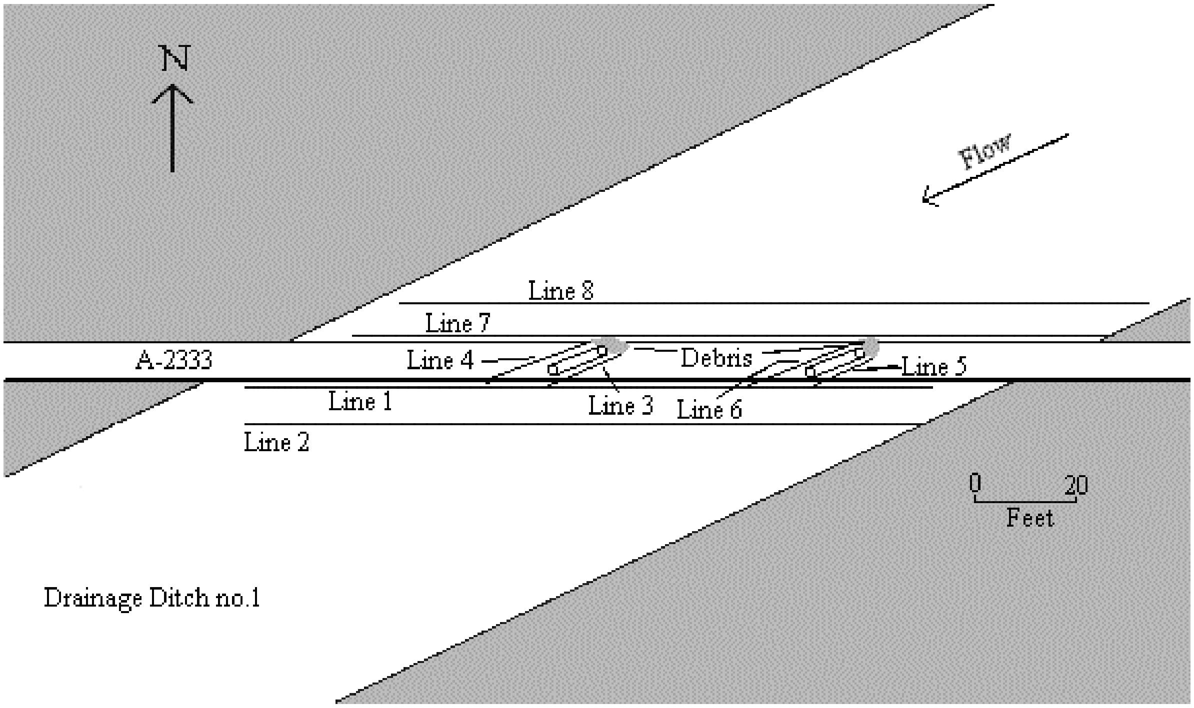

Figure 13. Survey Site 7 (Table 1), Drainage Ditch #1, Dunklin County, Missouri.

GPR Profiles Acquired Perpendicular to Current Flow

Selected, representative GPR profiles from three sites with different channel characteristics are presented in this section. Study Sites 1 and 9/10 are shown as Figures 15 and 16 respectively. Representative profiles are shown as Figures 17-18, 19-22-23-24, respectively. Note that river-bed sediment at all sites consisted of essentially clean clastics, and quality GPR images of sub-bottom strata were acquired. If significant clay had been present in the sedimentary section, the GPR tool would not have provided quality images of sub-bottom sediment.

Stacked and migrated profiles (both non-interpreted and interpreted), are presented for Profile 1, Site 1 (Figures 17 and 18). Stacked, migrated, and velocity-corrected profiles (non-interpreted and interpreted) are presented for the Profile 1, Site 9 example (Figures 19-22). Stacked and migrated profiles (non-interpreted and interpreted) are presented for Profile 7, Site 10 (Figures 23-24). Depth scales on the stacked and migrated profiles were calculated using EM water velocities only. The water depths on the migrated profiles are accurate, however depths to any sub-water bottom structures are inaccurate. The estimated depths on the velocity-corrected profiles were calculated using different EM velocities for water and sediment, and present a more accurate depth image of the water bottom and sub-water bottom sediment structure.

The gray lines on the interpreted GPR profiles represent the interpreted water bottom. The white lines across the GPR profiles represents reflections from the base of interpreted in-filled scour features. The thickness of in-filled scour features (represented by “S”) can be estimated by measuring the distance from the white line to the top of the gray line on velocity-corrected profiles. The maximum amount of scour and in-filled scour at each site is listed in Table 1. Piers along the profile are displayed as rectangular columns on the sections. Reflections from the flanks or footings of some of the piers are characterized as prominent diffractions on the GPR profiles.

Example Profile 2, Site 1: Site 1 bridge, located on Highway 60, crosses the St. Francis River near the town of Poplar Bluff, Missouri. The reflection from the water bottom (gray event) is clearly evident on the processed profiles (Figures 17 and 18). The data were migrated using the water velocity only. Water bottom depths (gray reflector) are most accurately depicted on the migrated GPR profile. Note that significant in-filled scour features were not identified on the GPR profile; hence velocity corrections were not applied. Note also that the GPR profile 2 crosses deeply incised scour features (about 8 feet deep).

Example Profile 1, Site 9: The Site 10 bridge, located on Highway 164, crosses a drainage ditch near the town of Kennet, Missouri (Table 1; Figure 16). The reflection from the water bottom is clearly evident on all of the presented GPR profiles (Figures 19-23). However, water bottom depths (gray reflector on interpreted GPR sections) are most accurately depicted on the migrated GPR profile (Figures 19b and 20b). Non-interpreted and interpreted stacked and velocity-corrected sections are displayed in Figures 14 and 15.

Example Profile 7, Site 10: The Site 10 bridge, located on Highway 164, crosses a drainage ditch near the town of Kennet, Missouri (Table 1, Figure 16). GPR profile 7 (Figures 24-25) was acquired perpendicular to current flow, and adjacent to a pier, however prominent diffractions from the pier footings are not evident on the stacked, migrated or velocity-corrected profiles. The reflection from the water bottom is clearly evident on all of the processed profiles. Water bottom depths (gray reflector) can be estimated most accurately from the analysis of the migrated GPR profile (Figure 24b). The depth and thickness of sub-water bottom layers (in-filled scour features) is accurately depicted only on Figure 25b. Evidence of two previous scour events is observed on the GPR profiles.

Conclusion

During high-flow stages streambed materials around bridge piers are frequently removed by floodwaters. This process can compromise the structural integrity of the bridge and in extreme cases, lead to failure or collapse. An understanding of local scour processes at specific bridge sites is therefore essential.

During the summer and fall of 1999, ground penetrating radar (GPR) data were collected, processed and interpreted in an effort to test this tool's ability to image water bottom and in-filled scour features in shallow Missouri waterways. Multiple GPR profiles were acquired at ten bridge sites, each of which was characterized by different channel characteristics.

Based on the analysis of the acquired data, we have concluded that GPR can be a useful, cost-effective tool for estimating water depths and identifying/mapping in-filled scour features. It is important to remember that GPR can provide detailed images of sub-bottom strata in clastic sedimentary environments. However, the GPR tool will not provide quality images of sub-bottom strata if significant clay is present.

References

Hayes, D.C. and Drummond, F.E., 1995, Use of Fathometers and Electrical Conductivity Probes to Monitor Riverbed Scour at Bridge Piers: U.S.Geologic Survey Water-Resource Investigation Report 94-4164.

Placzek, G., Haeni, F.P. and Trent, R.E., 1993, Use of geophysical data to assess scour development: National Conference on Engineering Hydrology Proceedings: American Society of Civil Engineers, 2051-2056.

Placzek, G. and Haeni, F.P, 1993, Surface geophysical techniques used to detect existing and in-filled scour holes near bridge piers, U.S. Geological Survey Report U-5015.

Vernier Software & Technology, 2000, Vernier Software & Technology User's Lab Manual.

Xanthakos, P., 1995, Bridge Substructure and Foundation Design: Prentice Hall.

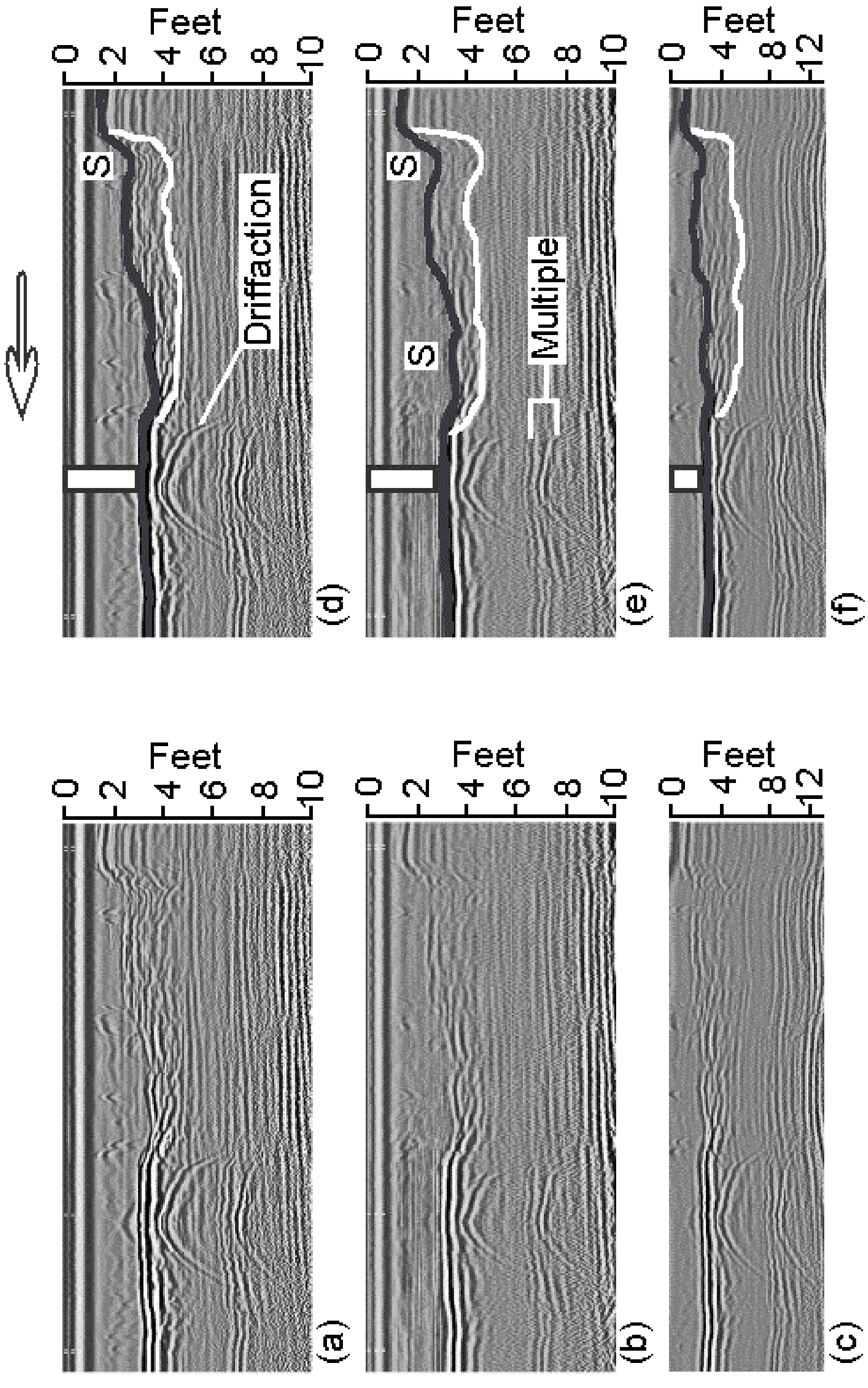

Figure 14. Profile 3, Site 7 (Figure 13): (a) stacked; (b) migrated; (c) velocity-corrected; (d) interpreted stacked; (e) interpreted migrated; and (f) interpreted velocity-corrected. Gray and white lines identify water bottom and extent of in-filled scour, respectively.

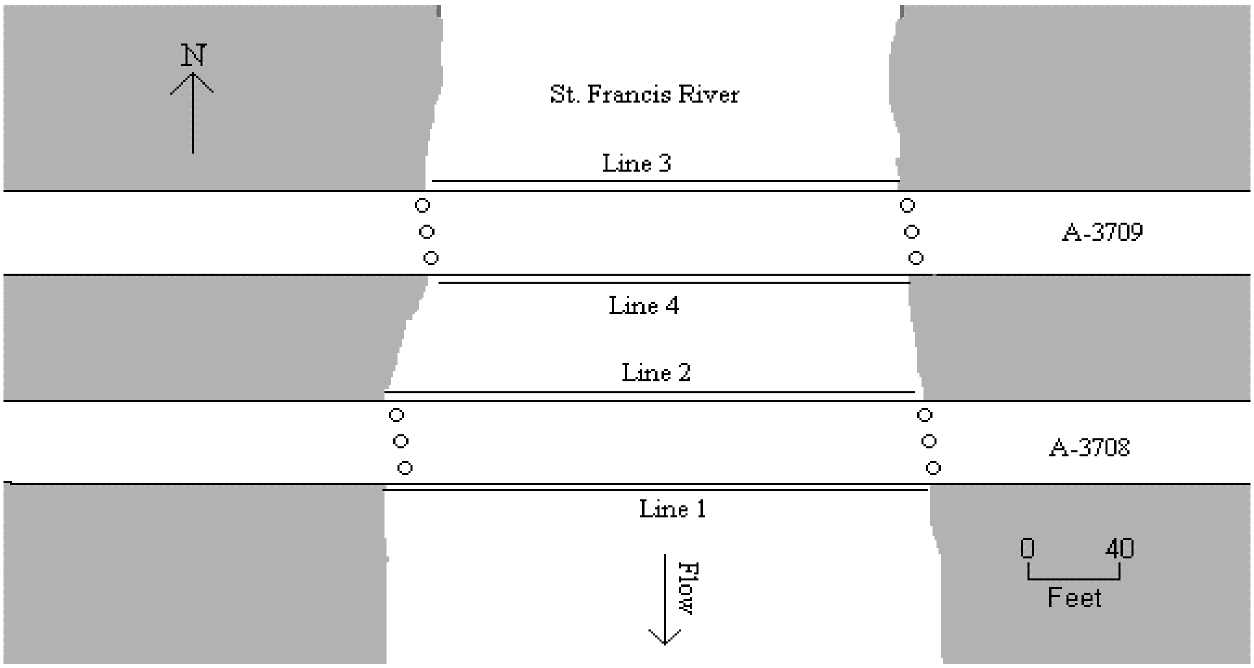

Figure 15. Survey Site 1 (Table 1), St. Francis River, Butler County, Missouri.

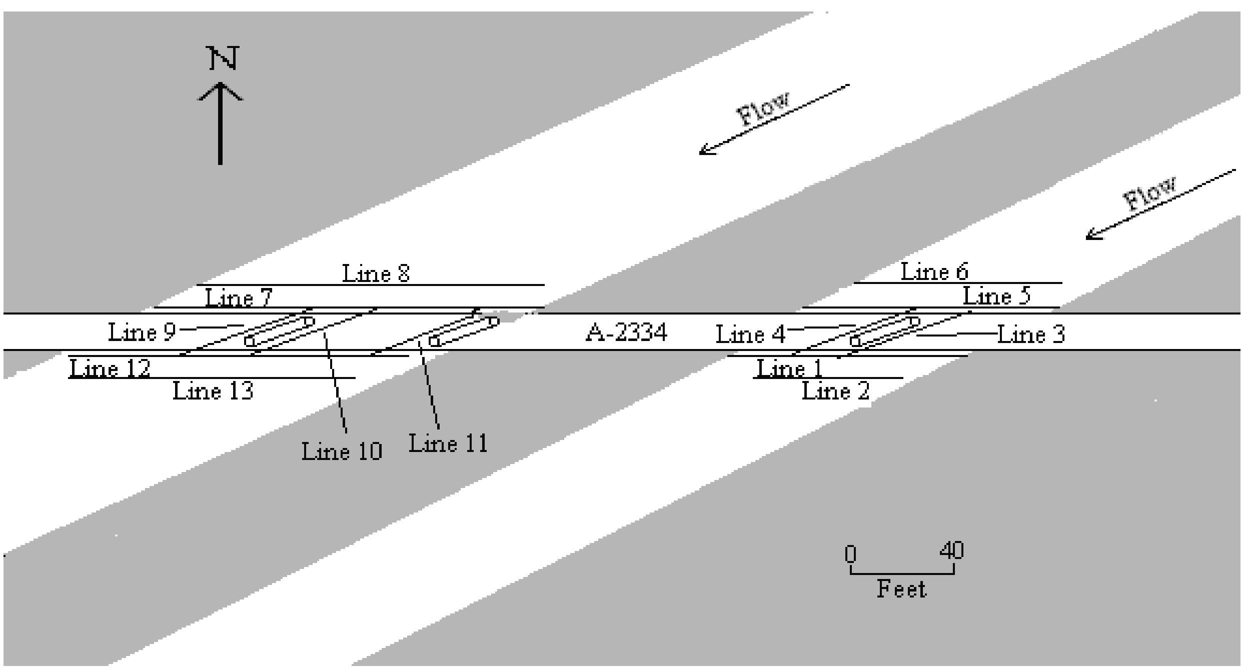

Figure 16. Survey Sites 9 and 10 (Table 1), Drainage Ditch #66, Dunklin County, Missouri.

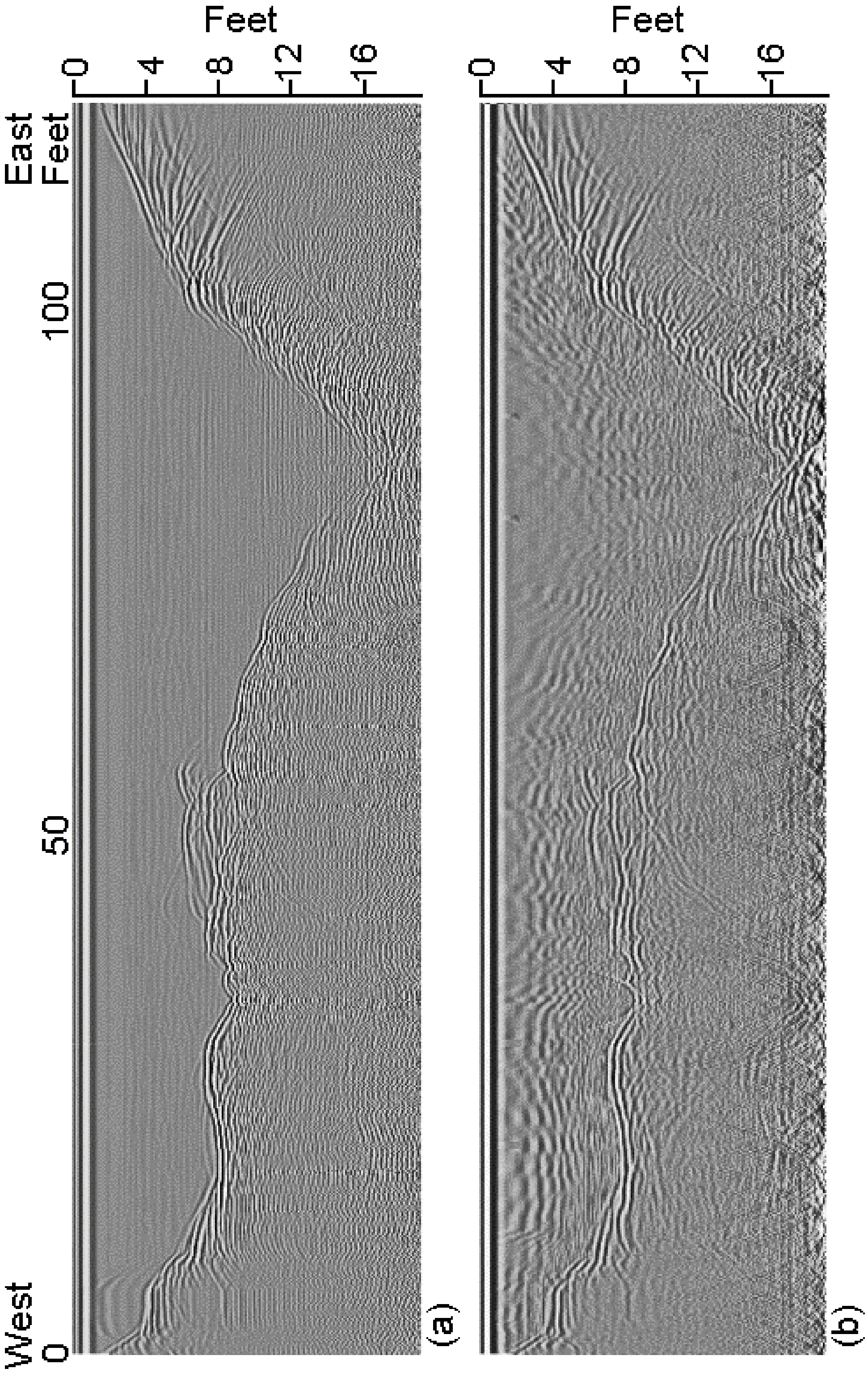

Figure 17. Profile 2, Site 1 (Figure 15): (a) stacked and (b) migrated versions.

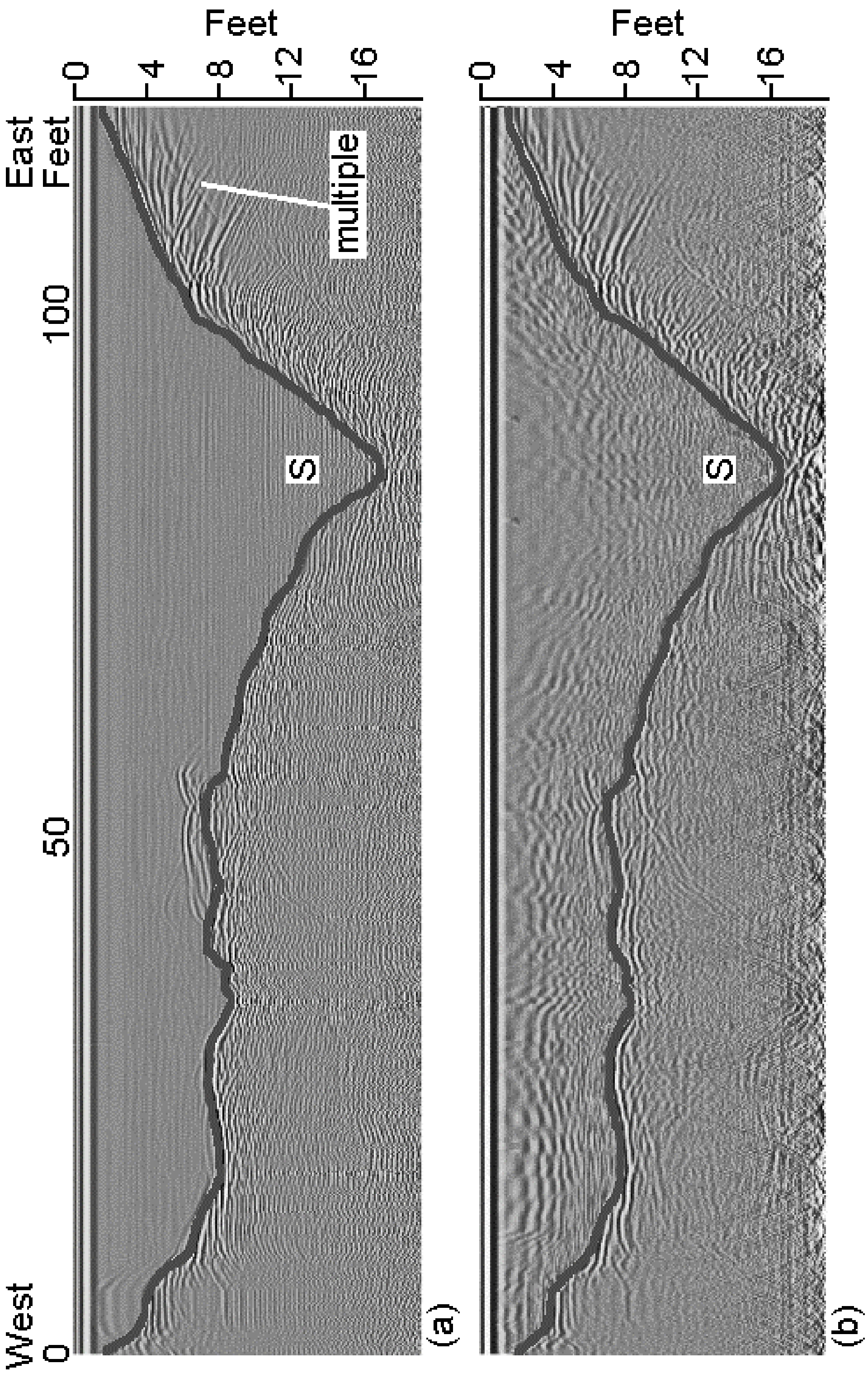

Figure 18. Profile 2, Site 1 (Figure 15): (c) interpreted stacked and (b) interpreted migrated versions. Gray line identifies water bottom. Existing scour feature is marked with an "S".

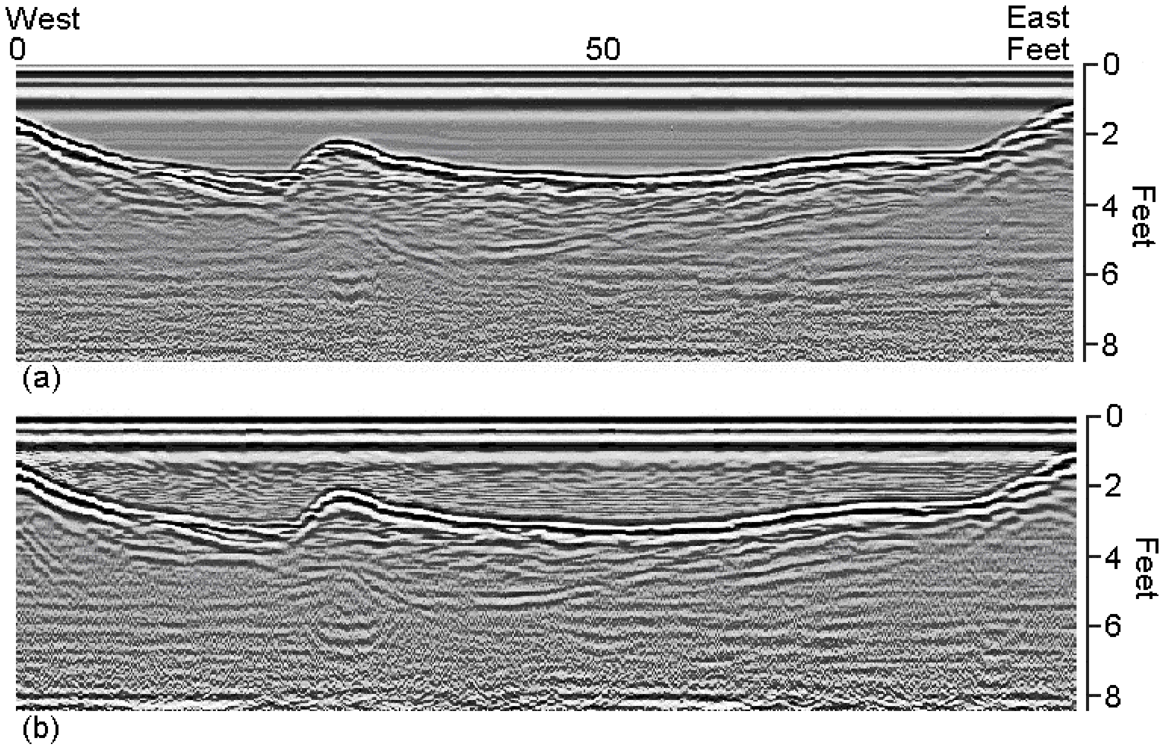

Figure 19. Profile 1, Site 9 (Figure 16): (a) stacked and (b) migrated versions.

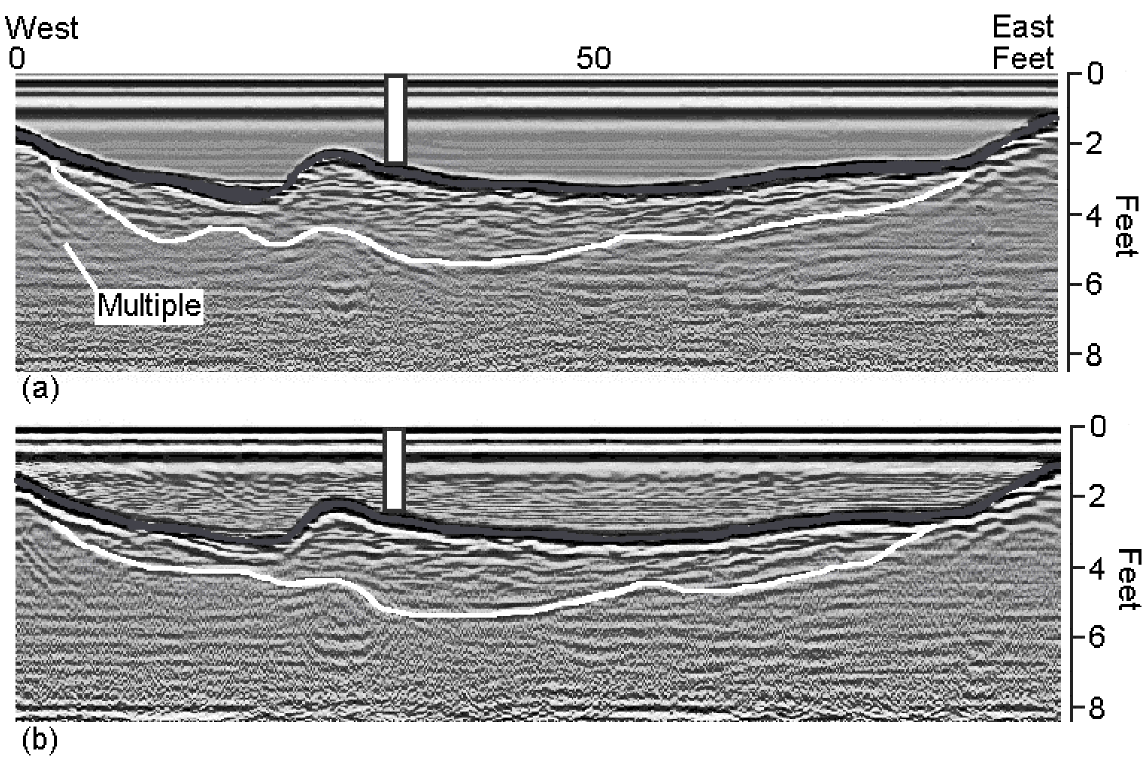

Figure 20. Profile 1, Site 9 (Figure 16): interpreted (a) stacked and (b) migrated versions. Gray and white lines identify water bottom and extent of in-filled scour, respectively.

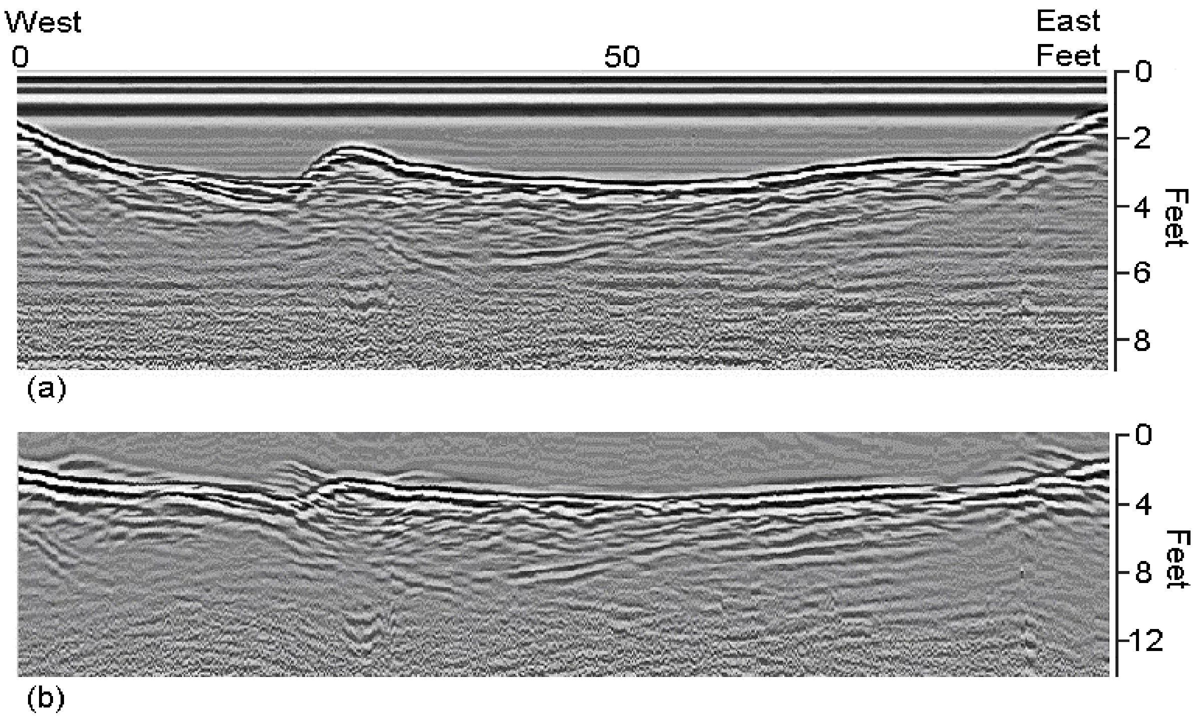

Figure 21. Profile1, Site 9 (Figure 16): (a) stacked and (b) velocity-corrected versions.

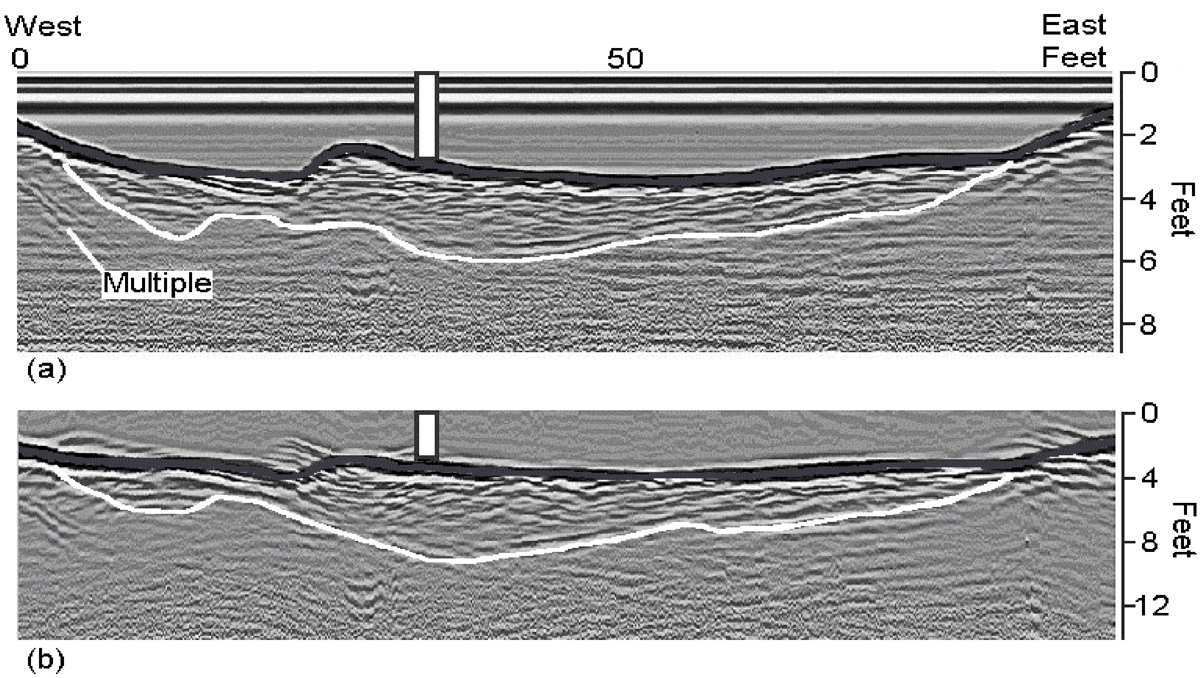

Figure 22. Profile 1, site 9 (Figure 16): interpreted (a) stacked and (b) velocity-corrected versions. Gray and white lines identify water bottom and extent of in-filled scour, respectively.

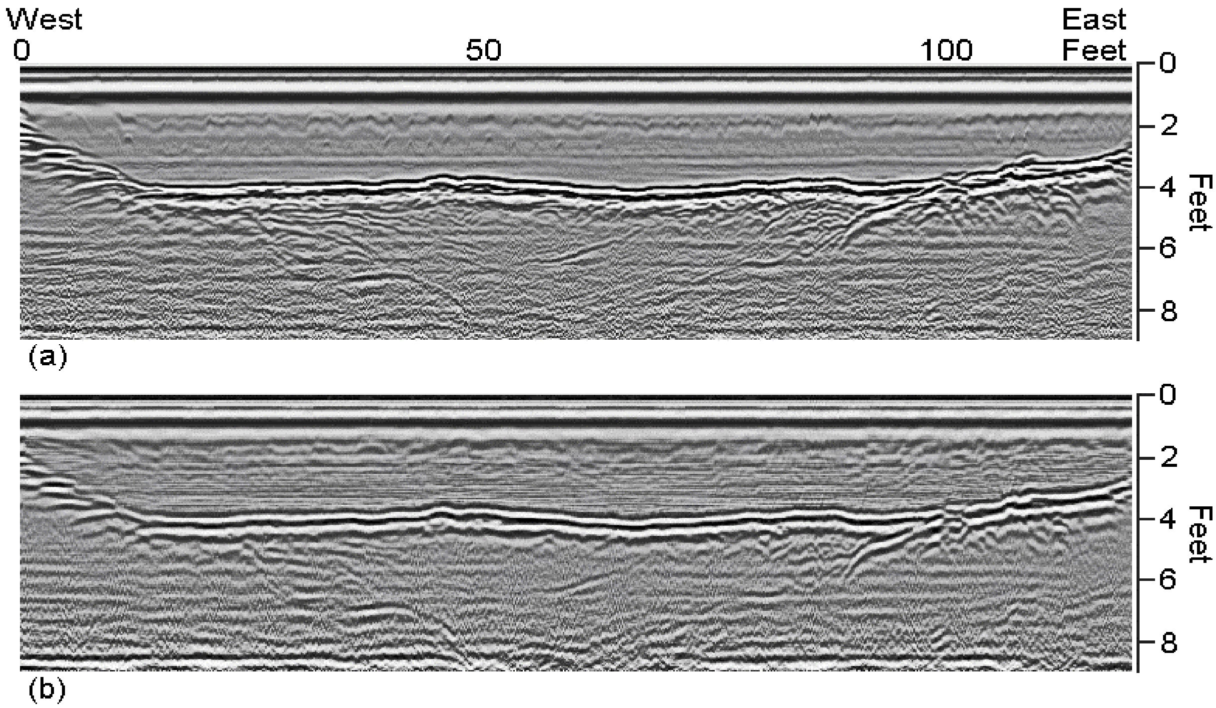

Figure 23. Profile 7, Site 10 (Figure 16): (a) stacked and (b) migrated versions.

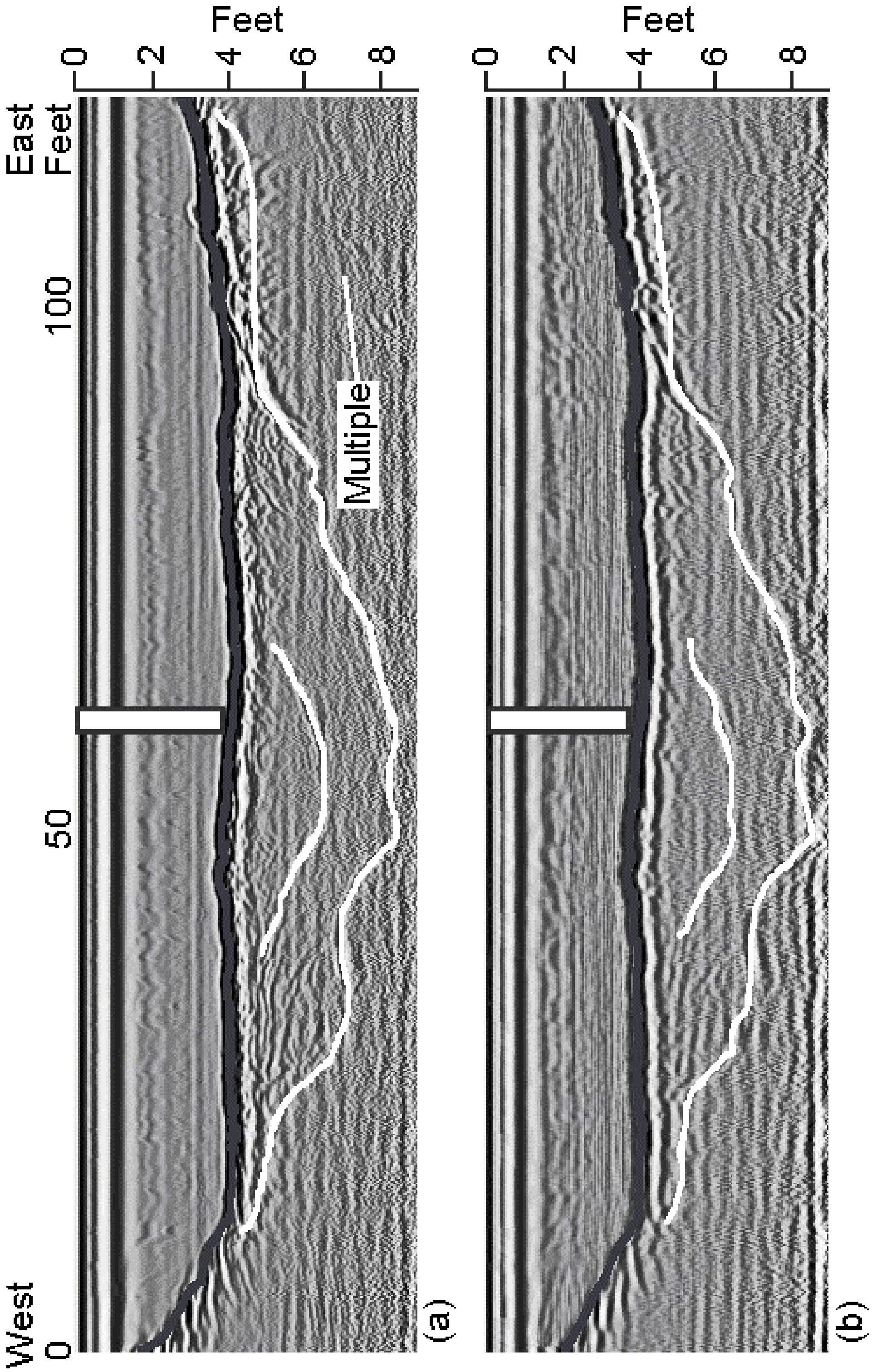

Figure 24. Profile 7, Site 10 (Figure 16): interpreted (a) stacked and (b) migrated versions.

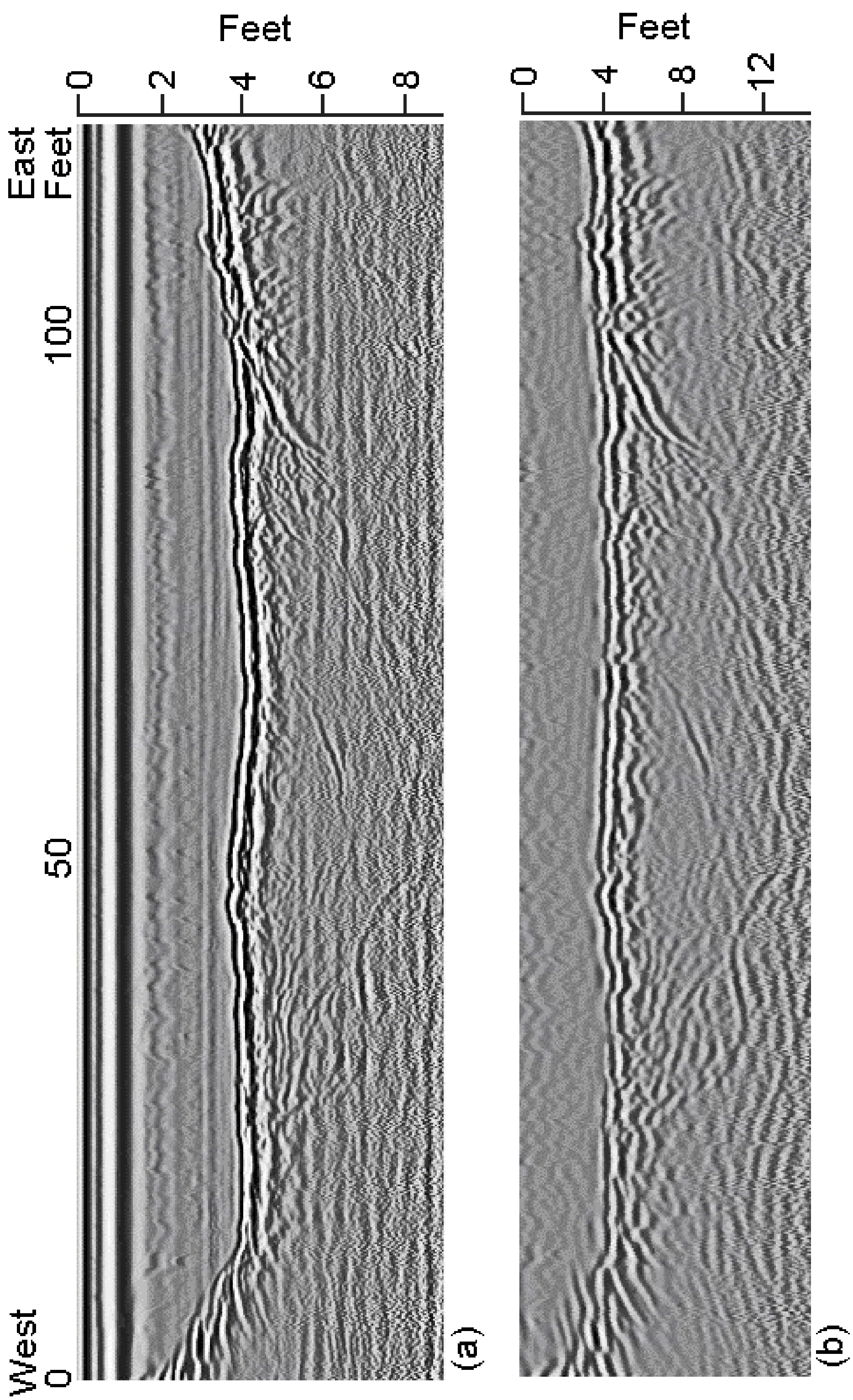

Figure 25. Profile 7, Site 10 (Figure 16): (a) stacked and (b) velocity-corrected versions.